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Exploration of Globular Dynamic Particle Systems

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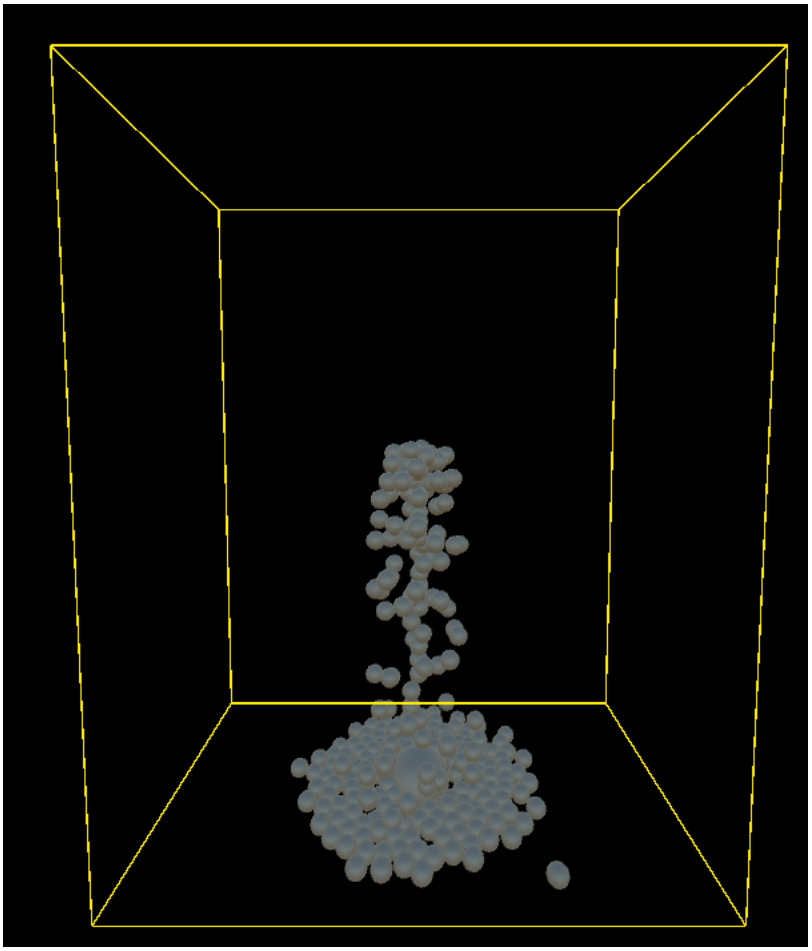

Figure 1: *Globular Dynamic Fountain*

Abstract

Our world is full of complex phenomena that computers have traditionally struggled to effectively simulate. With the modern advancements of computational power we are beginning to be produce real-time simulations for more of the worlds complex phenomena. Making using of particle based techniques has become a standard for the simulation of complex dynamic effects. We explored the simulation of viscous fluids making use of Miller and Pearces Globular dynamics presented in [MP89] for its real-time simulation and visual effectiveness over a range of complex dynamic substances.

CCS Concepts

• ***Computing methodologies*** → *Collision detection, Simulation evaluation, Model verification and validation;*

1. Introduction

Are world if full of complex interacting systems that present us with extreme difficulties when attempting to produce physically accurate simulations. Research in Computational Fluid Dynamics (CFD) has purposed many solutions for the simulation of fluids. However, many of these approaches are not well suited for real-time simulations. In this paper we will be exploring [MP89] purposed Particle-based Globular Dynamics technique and it's ability for real-time simulations of viscous fluids. Particle-based techniques provide us with a simplified yet powerful interface for the modeling of complex dynamic natural phenomena such as lava, mud, molten metals, sand, and oil.

2. Related Work

Particle-based techniques such as purposed in [Ree98], [MP89], [MCG03], and [GM77] have been used extensively for the simulation of complex natural phenomena. [Ree98] and [GM77] purposed the advantages particle based-techniques have over the classical surface-oriented techniques for modeling complex dynamic phenomena. While, [MCG03] purposed a method based on Smoothed Particle Hydrodynamics (SPH) for the simulation of fluids in real-time interactive applications. Following the work in [MCG03] we conducted a exploration into real-time simulation of viscous fluids using Globular dynamics purposed by Miller and Pearce in [MP89].

Typically the modeling of fluid dynamics makes use of the famous Navier-Stokes equations formulated by Claude Navier and George Stokes. However, we will be exploring the Globular dynamics system presented by Gavin Miller and Andrew Pearce in [MP89] for its ability to simulate various viscosity fluids without the complexities imposed by the Navier-Stokes method.

3. Overview

The expressed particle system incorporates the mathematical models presented by Miller and Pearce [MP89] with modification provided by [Rin] for simulating viscous fluids. Viscous fluids we desire to model all flow with some level of opposing directional force such are oil, lava, and malleable or molten metals. The presented Eulerian particle system incorporates interparticle, gravitational, and environmental Newtonian forces.

3.1. Interparticle Forces

Particles within the system influence each others by applying repulsion, attraction, and dampening forces. Magnitude and type of force that will be applied to a given particle is based on the distance, material, compressibility, positional difference, and velocity difference of all near by particles calculated as:

$$F_p = \sum_{i=0}^{N} f_{ip} \tag{1}$$

where,

$$f_p = \begin{cases} \overrightarrow{P_\Delta}[s_r(\frac{b_1}{D^m} - \frac{b_2}{D^n}) - (s_d * b_d)(\frac{\overrightarrow{V_\Delta} \cdot \overrightarrow{P_\Delta}}{D^2})] & i \neq p \\ 0 & i = p \end{cases} \tag{2}$$

Variable b_1 is set by the user and determines the strength of repulsion forces. While, b_2 controls the attraction forces and is calculated as $b_2 = \frac{b_1}{(r_i + r_j)^2}$ where r is the radius at which balance between interparticle repulsion and attraction forces are achieved. While variable b_d introduced by [Rin] is a user set dampening scalar for fine tuning of dampening forces. Furthermore, m and n are constants that specify the magnitude of repulsion and attraction forces over distance. To keep consistency with [MP89] our system will set m=5 and n=3. Variables $\overrightarrow{P_\Delta}$ and $\overrightarrow{V_\Delta}$ reference the positional difference and velocity difference between two particles and are given by:

$$\overrightarrow{P_\Delta} = P_p - P_i \tag{3}$$

$$\overrightarrow{V_\Delta} = V_p - V_i \tag{4}$$

Scalars s_r and s_d control the magnitude of repulsion/attraction and dampening forces exerted based on the material type specified by the constants c_r and c_d.

$$s_r = \begin{cases} 1 - \frac{D^2}{c_r^2(r_i + r_p)^2} & D^2 < c_r^2(r_i + r_p)^2 \\ 0 & D^2 \geq c_r^2(r_i + r_p)^2 \end{cases} \tag{5}$$

$$s_d = \begin{cases} 1 - \frac{D^2}{c_d^2(r_i + r_p)^2} & D^2 < c_d^2(r_i + r_p)^2 \\ 0 & D^2 \geq c_d^2(r_i + r_p)^2 \end{cases} \tag{6}$$

3.1.1. Liquids

Simulating a liquids we set the material constants to $c_r = r_o$ and $c_d = 2r_0$, where $r_0 r$ specifies a particles radius of influence. Setting $c_r = 1$ and $c_d = 2$ results in a low viscosity substance (fig. 2) that tends to cluster near by particles while preventing compression by exerting a repulsive force when particles overlap. By increasing r_0 and or b_d we can model increasingly viscous liquids. However increasing r_0 or b_d can result in increasing instability in particle clusters attempting to converge on to a resting state.

3.1.2. Solids

Simulation of a viscous solid such as molten metals can be done by setting the material constants to $c_r = 2r_0$ and $c_d = 2r_0$. The particle interactions result in strong clustering of particles due to the increased attraction and even dampening. Keeping consistency with [MP89] setting $c_r = 2$ and $c_d = 2$ results in a flow-able solid that attempts to keep particles clustered while being malleable enough to deform as force is applied (fig. 3). The attempt to simulate more rigid solids by increasing r_0 or b_1 tends to become unstable when large amounts of particles cluster.

3.1.3. Powder

Material constants of $c_r = r_0$ and $c_d = r_0$ produces a powder like substance that has minimal particle interactions. setting $r_0 = 1$ we

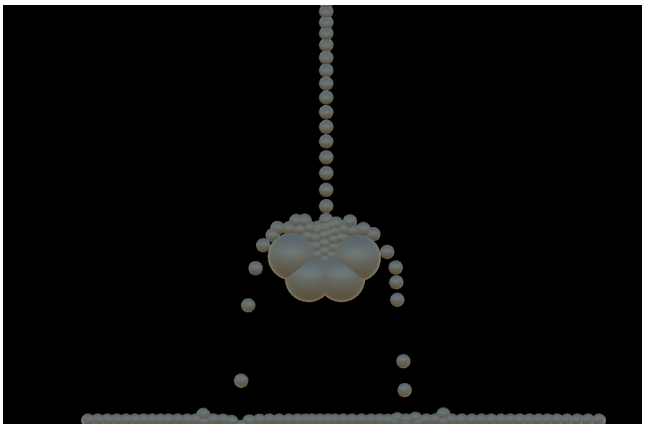

Figure 2: *Liquid Simulation*

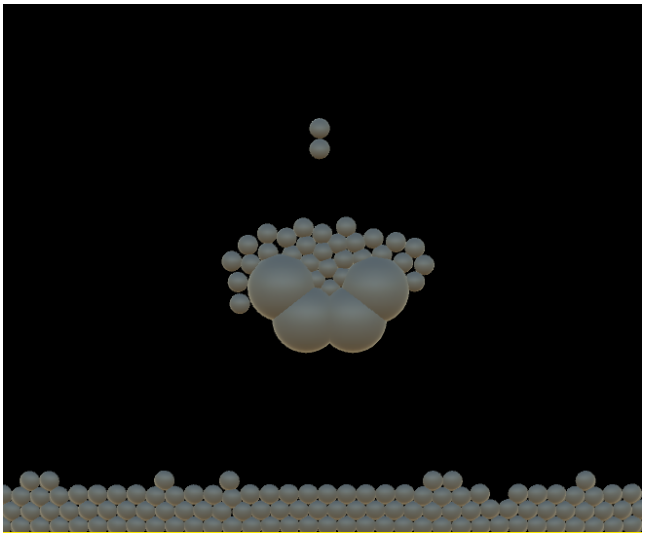

Figure 3: *Solid Simulation*

can simulate substances where individual particles are more independent of each other (fig. 4). This parametrization is well suited for substances such as sand that tend to have little particle-particle interactions outside of particle-particle collisions.

3.2. External Forces

There are many types and methods of implementing external forces into a particle system. We went for a impulse-based approach that makes use of globular dynamics (eqn. 3.1) force calculations to produce collision repulsion forces. Making use of globular dynamics force equation (eqn. 3.1) for collisions enables dynamic soft collisions that produced a more natural effect over spring based solutions. Collision detection of this nature needs to deal with two main cases spherical-particle collisions and planar-particle collisions.

The simpler case of spherical-particle collisions we create a spherical object that applies repulsion forces to particle that get near in a similar fashion to how particle-particle interactions where

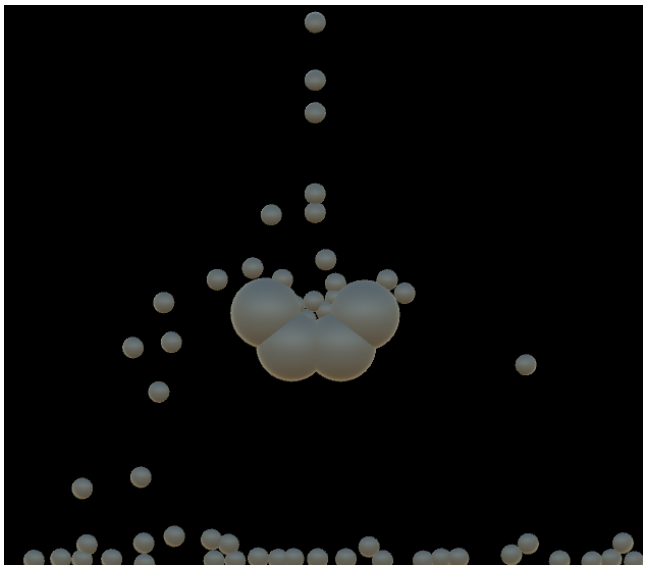

Figure 4: *Powder Simulation*

conducted. While the more interesting case of planar-particle collision we detect particle intercept with the planar surface using a AABB-sphere collision approach. When collision has been detected we generate a repulsive force object centered at the closest point on the planar surface to the colliding particle offset into the planar surface by the radius of the repulsion object. The generated objects used for repulsion in our simulation only interact with the colliding particle and are of radius $r = 0.5$ with $b_1 = 10$, $c_r = 1$, $c_d = 1$, and $b_d = 5(c_{dp})$ where c_{dp} is the colliding particle's material constant c_d.

This approach to constraint collisions creates dynamic soft impacts for particle constraint collision in a similar fashion to springs. Additionally, making use of the globular dynamics force calculations gives us the ability to fine tune collision specifications more widely then spring implementations. However, making use globular dynamics forces for collision comes with the disadvantage of particle moving at high speeds being able to skip/jump outside the force range thus completely bypassing the collision penalty forces.

3.3. Integration

Miller and Pearce state that the method of integration is dependent on the implementation of external forces [MP89]. Additionally, Miller and Pearce express that only Eulerian integration produces a continuous solution when impulse-based external forces are used [MP89]. Due to the above statements from Miller and Pearce our system makes use of symplectic Euler integration for calculating particle motion.

$$v_p(t_1) = v_p(t_0) + \frac{1}{M_p}\int_{t_0}^{t_1} F_p dt \tag{7}$$

$$x_p(t_1) = x_p(t_0) + \int_{t_0}^{t_1} v_p(t_1) dt \tag{8}$$

Simulation	r	b_1	b_d	c_r	c_d
Liquid	0.15	0.01	1	1	2
Solid	0.15	0.8	4	2	2
Powder	0.15	0.8	4	1	1
Fountain	0.15	0.01	1	1	2

Table 1: *Simulation Parameterizations*

Number of Particles	Calculation Time (ms/frame)
100	2.3
1000	11.9
1100	21.7
1200	124.5
1300	436.4
1400	494.9
1500	569.5
2000	627.4

Table 2: *Simulation Performance*

4. Evaluation

Our Globular dynamics particle system achieves very promising visual results for the simulation of viscous fluids. The simulation of liquids, as displayed by fig.2 and fig.1, produces a dynamic and dampened flow of particle that is visually consistent to the expected motion of various viscosity substances. However, we discovered when attempting to model very high-viscosity substances such as honey or jam that the instability and visual issues arise. The stability and visual issues we discovered with the simulation of high-viscosity liquids are caused by the increase of terms b_d and c_d resulting in large particle clusters where dampening forces become exponentially large causing particle force instability. Simulation of solids, as depicted by fig.3, we found produce results that are very well suited to substances such molten metals. However, when attempting to simulate solids using Globular dynamics that are more rigid and resistant to external forces by increasing b_1 to acquire increased particle-particle attraction that instability occurs when a impulsive forces is applied to a body of clumped particles. The resulting instability is a direct result of increasing b_1 in the attempt to increase particle-particle attraction, this is because by increasing b_1 we not only increase attraction but also repulsion forces applied to particles. Thus, when a impulsive force acts on a cluster of particles the instant shock causes a large exertion of repulsion forces to be applied to the particles inside the cluster. Finally, the simulation of powder like substances, depicted by fig.4, results in the most stable but limited simulation case. Due to particle independence of the parameterization of powders we did not see the same extent of instability issues presented by solid or liquids. However, caution when selecting the value of b_1 is still needed to prevent instabilities caused by impulsive forces.

Performance wise our Globular dynamics particle system produced promising outlook for usability in real-time simulations. As outlined by Miller and Pearce in [MP89] their Globular dynamic particle system is bound by n^2 time, with the ability to run at n time by culling calculations of particles that are of sufficient distance to not have any interaction forces between them. Our particle system made use of the calculation culling described by Miller and Pearce [MP89] and resulted in the performance metrics shown by 2 on a Nvidia RTX 4080, 3.4Ghz Ryzen 7, and 32GB of memory system. Analysing the performance results shown in 2 we see that after 1000 particles our system rapidly decays in performance due to prolonged calculation times between particles. However, the rapid performance decay shown by our system could be improved with optimization techniques such as spatial subdivision outlined in [Gre10], or parallel computation and improved GPU utilization. With improvements and optimizations to our system it is promising that we would be able to achieve real-time performance for the simulation viscous fluids.

5. Conclusion

With the rapid growth of computation power real-time simulation of complex phenomena is becoming ever more feasible at a large scale. We presented and explored the globular dynamics particle system presented by Miller and Pearce in their paper Globular dynamics: A connected particle system for animating viscous fluids [MP89] for its real-time simulation effectiveness with modern computer hardware. We found that Globular dynamics provides a promising approach for the real-time simulation of viscous fluids such as lava, molten metals, and oils. Additionally, we showed some of the difficulties and limitations imposed by the use of Miller and Pearces Globular dynamics when attempting to simulate more extreme phenomena. Furthermore, addition research and develop into optimization techniques need to be done for the validation of larger scale real-time simulations using globular dynamics. In conclusion Miller and Pearces globular dynamics particle system provides promising results in real-time simulation complex viscous fluids while producing visually accurate results of such substances.

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